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Title:

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Submitted to:

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FORM 836 (10/96)

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Seismic Analysis of the 12 August 2000 Kursk Submarine Disaster in the Barents Sea

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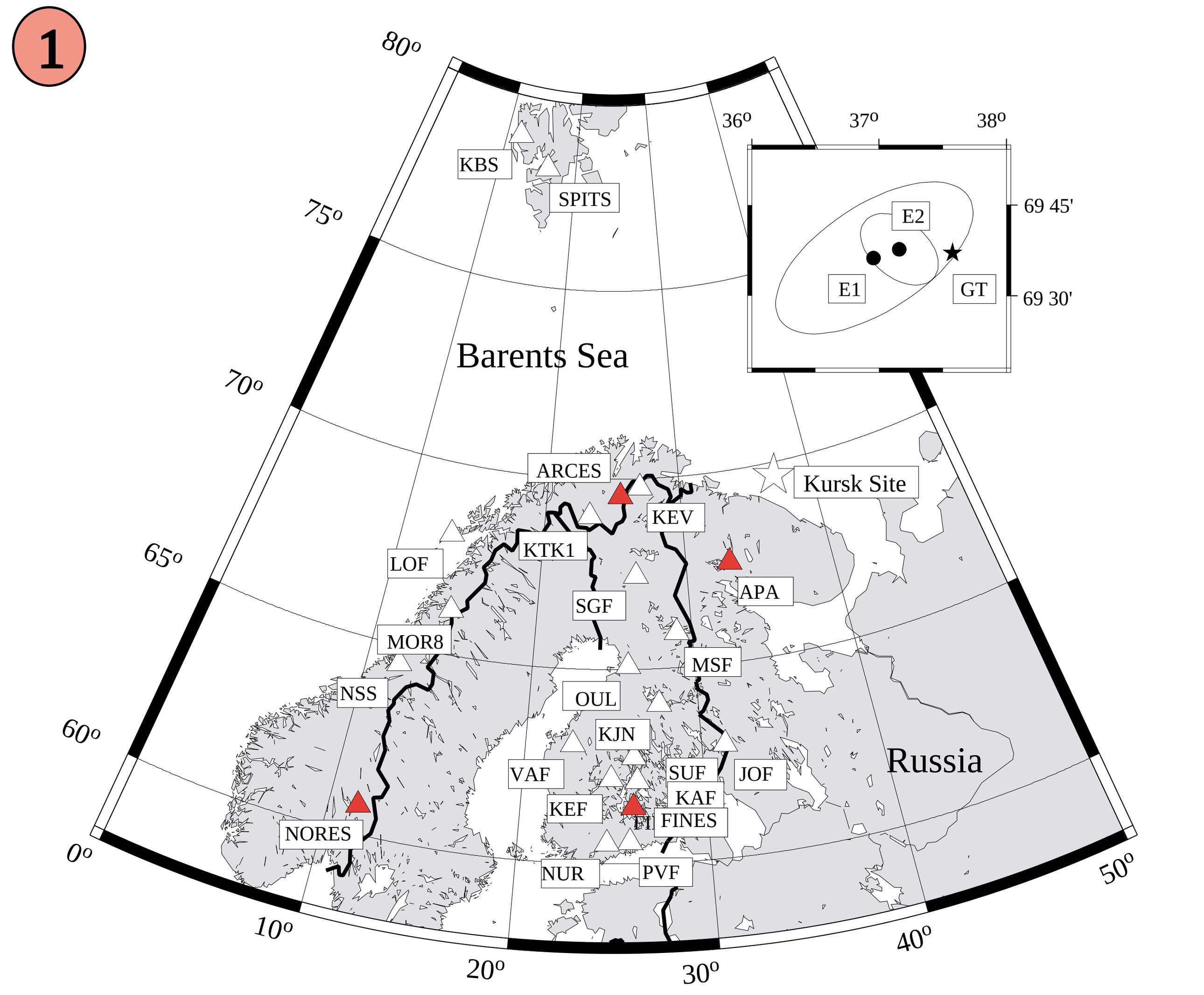

Figure 1. Locations of regional distance seismic stations which recorded the Kursk event. Three component stations are shown as white triangles and short period array stations are shown as red triangles. The inset shows our locations and error ellipses for the precursory event (E1) and the main event (E2). The actual position (GT) of the downed sub is indicated by the star.

Introduction

On 12 August 2000 the most advanced attack submarine in the Russian fleet sank in the Barents Sea about 70 km off the coast of the Kola Peninsula. Details of the accident that caused the Kursk to sink were shrouded in secrecy and propaganda. It is known that the accident was related to a series of explosions, and owing to the high efficiency of coupling in underwater explosions these explosions generated a seismic signal of sufficient magnitude (4.2 M_l, 3.4 m_b) to be recorded by seismometers as far as 5000km away. The main Kursk event on August 12 was detected and automatically located by at least four independent monitoring groups. The preliminary locations are:

Univ. Helsinki:	69.67°N	37.53°E	07:30:41.9
Univ. Bergen:	69.58°N	38.03°E	07:30:42.6
NORSAR:	69.67°N	37.25°E	07:30:42.0
PIDC:	69.58°N	37.92°E	07:30:42.2

The differences in location, which are negligible, are due to the different techniques, models and data sets. The seismic signal can be positively associated with the Kursk incident due to origin time and lack of previous seismicity in the region.

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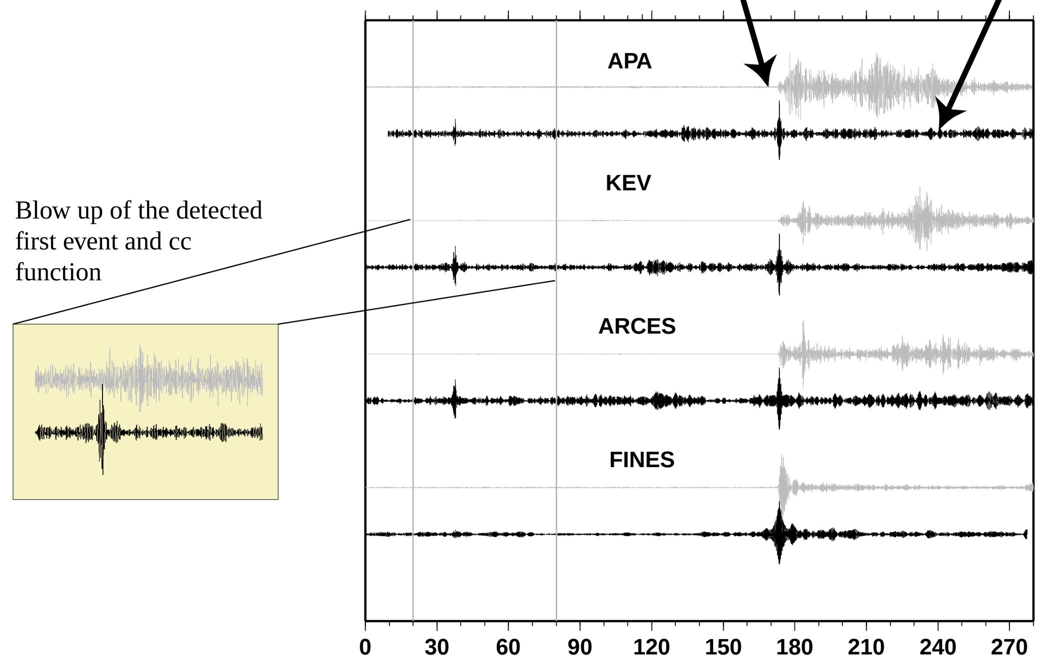

Figure 2a. Application of the Waveform Correlation Detector of Wiechecki Vergara [2000] to the Kursk data. The actual waveforms are shown in gray, while the crosscorrelograms are shown in black. A precursory event is clearly visible with at a lag of 135.75 s. The similarity of the precursory waveform with the main waveform is such that the two events must have occurred at nearly identical locations and with similar source mechanisms. We applied the WCD for a time span of +/- 24 hours with respect to the main Kursk event and found no other statistically significant peaks.

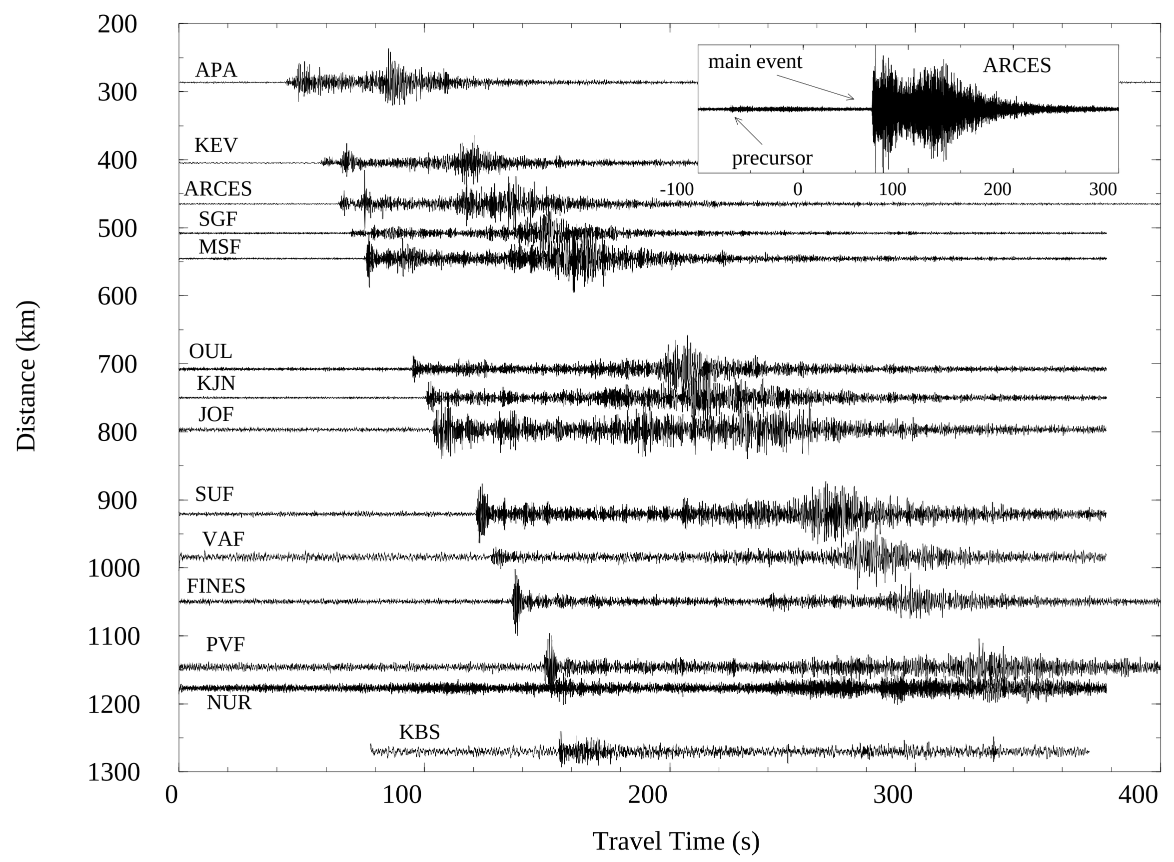

Figure 2b. Vertical component record section of the main Kursk event. Each trace has been highpass filtered and normalized to a common scale. P_n and L_g phases are clearly visible at all distances although their ratio, and the ration of compressional to shear energy in general, has large variability. The inset shows the relative size of the two Kursk events from an element of the ARCES array.

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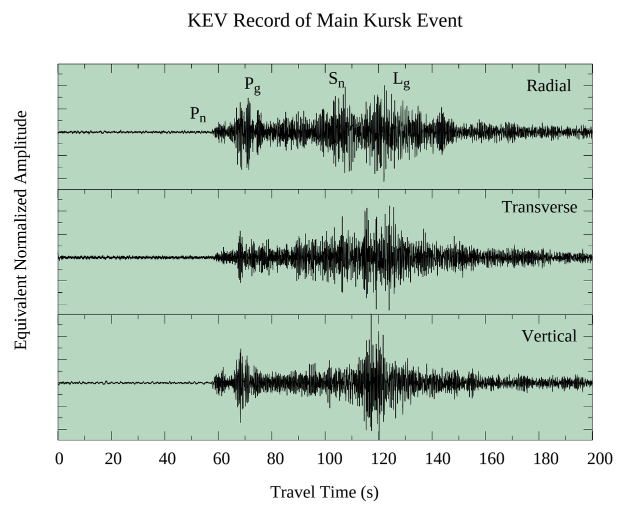
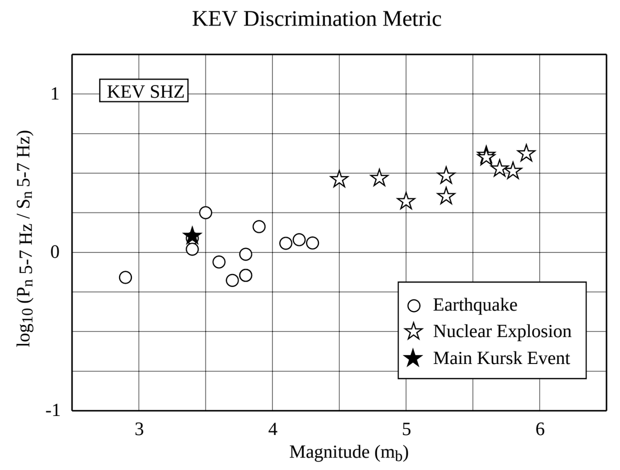


Figure 3a. Broadband KEV record of the main Kursk event. The data have been highpassed at 1 Hz. Amplitudes are normalized to a common scale.

Figure 3b. The ratio of compressional to shear energy for a series of explosions and earthquakes recorded at KEV. The main Kursk event falls in with the earthquake population owing to its large shear wave amplitude. Details on the calculation can be found in Hartse [1998].



Source Complexity

As seen in Figure 2b, many of the Kursk waveforms have strong shear arrivals. The KEV data in particular, Figure 3, have anomalously large shear energy when compared with some previously recorded explosion waveforms.

A second puzzling feature of the Kursk data is that several, but not all, records have dilatational (downward) first motions. Generally waveforms from explosive sources have consistently compressive (upward) first motions.

Presently, it is not clear why the Kursk waveforms show such complexity, however there are several factors that may have contributed:

(1) Asymmetries induced by the positioning of the Kursk as it lay on the seafloor just before exploding.

(2) Energy generated by the impact of the Kursk with seafloor, assuming a simultaneous impact/explosion scenario.

(3) Enhanced mode conversion owing to a surface focus.

(4) Enhanced scattering along source-receiver paths

(5) Substantially different source phenomenology for underwater explosions compared to atmospheric explosions.

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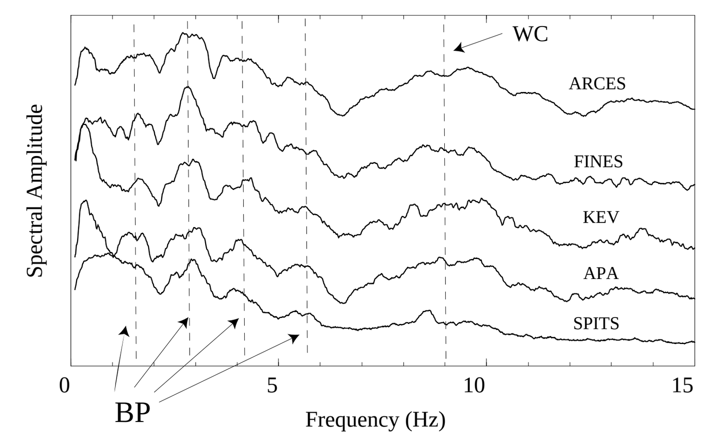

Figure 4a. Spectral amplitudes from several array stations and KEV. Time windows were chosen to bracket the P energy and the spectra have been stacked and smoothed. The spectral peaks indicated by the dashed lines are related to the bubble pulse (BP) oscillations and water column (WC) reverberations.

Bubble Pulse Observation

Underwater explosions generate bubbles of hot gases which expand and contract as they rise to the surface. These oscillations are effective seismic sources and produce periodicities in the waveforms known as bubble pulses. The spectral peaks shown in Figure 4a,b are indicative of the bubble pulse from the main Kursk event.

The dominant bubble pulse frequency, f_b, of an underwater explosion is most dependent on explosive yield and depth of detonation. We observed an f_b of 1.45 Hz for the main Kursk event, leading to a yield estimate of 3000-4500 kg TNT if the detonation occurred at 80-100 m. Note that this frequency, as well as its overtones, are much too low to be associated with water column reverberations.

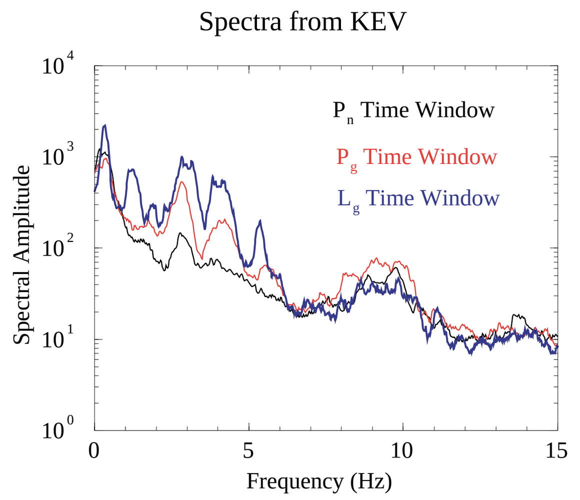

Figure 4b. Smoothed spectra from the vertical component, short period (100 sps) instrument at KEV. Time windows were chosen to bracket three different arrivals: Pn, Pg, and Lg. Peaks and troughs due to the bubble pulse and reverberations in the water column are visible.

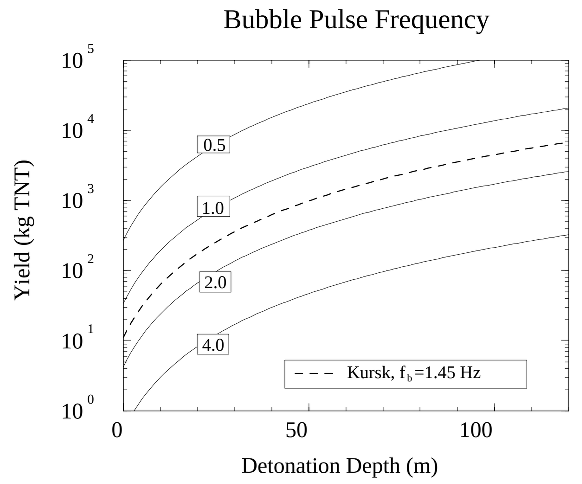

Figure 4c. The analytical dependence of bubble pulse frequency, f_b, with explosive yield and depth of detonation [Willis, 1941; Cole, 1948] . Lines of constant frequency are shown, and the Kursk f_b of 1.45 Hz is indicated by the dashed line.

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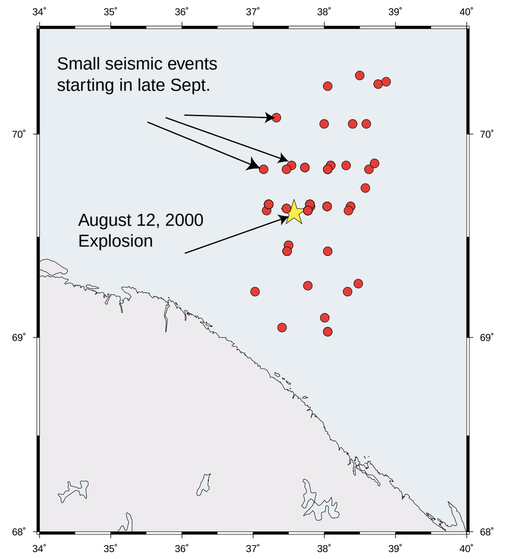
Post August Seismicity



Between August 13 and mid September 2000 there was no seismicity in region around the Kursk. However, since September 22 there have been more than 44 seismic events detected in the region (the locatons shown to the left were located with PMEL and the August 12 event as ground truth). The events are clustered in time: every few days there are 2 to 9 events, and then several days of no events. The majority of the events are magnitude ML 1.4-1.6, although some events are as large as 1.82.

In November, CNN reported that the Russians were using depth charges to discourage foreign submarines from visiting the wreakage.

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Comments on Yield

The absolute yield of the main Kursk event is best determined by comparison with previous records of controlled underwater explosions. Such records exist for a series of calibration shots carried out in the Dead Sea in November, 1999. For the largest of the Dead Sea shots, 5,000 kg high explosive at a depth of 70 m, the IMS reported an M_l of 4.2; this is not significantly different that the M_l of 4.0 that the IMS reported for the Kursk event. Furthermore, the array station GERES recorded both events, at almost identical distances, and reported m_b values of 3.3 and 3.4. This yield estimate of ~ 5,000 kg is roughly consistent with the bubble pulse estimate.

An absolute yield estimate for the precursory Kursk event is difficult to obtain, however its yield relative to the main event can be estimated by considering the difference in magnitudes reported by ARCES, 2.2 M_l and 4.0 M_l. Using a relation based on a wide range of explosion seismograms [Khalturin, 1998], this magnitude difference of 1.8 units corresponds to roughly 250 times less energy released by the precursory explosion.

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Conclusions

-- The main Kursk event on 12 August 2000 was seismically recorded at distances of over 5,000 km, and released energy equivalent to 3-7 x 10^3 kg TNT.

-- Owing to the clear observation of a bubble pulse, the main event was the direct result of an explosive source and not an impact or collision.

-- A precursory event with an essentially identical location to the main event occurred 135 s before the main event. The precursory event had an energy that was approximately 250 times less than that of the main event.

-- The high degree of similarity between the precursory waveforms and the main event waveforms supports the idea that not only were the two events located at nearly the same position but that they had similar source mechanisms as well.

-- It is most likely that the precursory event was a disabling explosion which directly or indirectly led to the catastrophic explosion 135 s later.

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Acknowledgments

Several colleagues helped in the retrieval of the open seismic data including Timo Tiira of the University of Helsinki, and Berit Marie Storheim and Eystein Husebye of the University of Bergen. Our interpretations of the seismograms benefited from discussions with Don Helmberger and Brian Savage at Caltech, Doug Baumgardt at ENSCO, and Hilmar Bungum at NORSAR. Kevin D. Hutchenson and Stephen Wiechecki Vergara made important contributions to the analysis.